Catena 78 (2009) 285–300

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Irrigation on the Tehran Plain, Iran: Tepe Pardis — The site of a possible Neolithic irrigation feature?

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ARTICLE INFO

Article history:
Received 27 November 2007
Received in revised form 29 January 2009
Accepted 9 February 2009

Keywords:
Water management
Tehran Plain
Iran
Neolithic

ABSTRACT

This paper presents direct evidence in the form of a triangular cross-section channel (1 m in width and 0.24 m in depth), for Late Neolithic artificial water management on the Tehran Plain, which may represent the earliest example of artificial water management in Iran. The antiquity of this channel is supported by dating directly above and below by C^{14}, associated ceramic sherds and correlation with Late Neolithic levels. The nature and function of this channel is evaluated through comparisons with natural channels (ancient and modern) together with evidence from palynology and sedimentology. It is here interpreted as a silted-up artificial canal with infill-deposits that indicate periods of shallow relatively quiet flow, periods of drying-out and occasional episodes of greater flow. This study strongly suggests that 6th millennium farmers at Tepe Pardis in Iran were irrigating their crops, and complements the evidence from Choga Mami in Iraq concerning early irrigation systems.

1. Introduction

The antiquity of water management, and its impact on the social and economic networks of the ancient Near East has long been discussed by archaeologists and historians (Childe, 1942, pp. 78; Hole and Flanney, 1967, pp. 181). These discussions reached fever pitch in the 1960s with the major landscape studies of the Susiana and Deh Luran plains of western Iran, where botanical, locational and environmental evidence was utilised to identify artificially irrigated agriculture in the archaeological sequence (Adams, 1965; Hole et al., 1969). So convincing were their arguments, that general archaeological textbooks and more specialist publications now stress the presence of artificial irrigation across much of the region by the 'Ubaid period (c. 5900–4200 BC) (Pollock, 1999; Matthews, 2003; Wilkinson, 2003). As this view is so widely accepted, it is surprising that the only direct evidence consists of a single irrigation channel excavated between 1967 and 1968 in eastern Iraq (Oates, 1969, pp. 125; Oates and Oates, 1976), and supported by the presence of one radiocarbon date calibrated to between 6200 and 5325 BC at 95% confidence (BM-483). However, note should also be made here of Prickett (1986) study of the Daulatabad channels in eastern Iran, which were found within the context of chalcolithic mounds (but not dated via C^{14}). We suggest that the Oates and Oates (1976) discovery could now be supplemented by a second radiometrically constrained example, identified during the recent excavation of Tepe Pardis, a tell site in the Tehran Plain (Coningham et al., 2006; Fazeli et al., 2007). Associated with Late Neolithic levels, this newly discovered feature is triangular in profile and notably different from several natural channels that were also present within the study area. Augmented by additional evidence from palynological and sedimentological analysis, this paper evaluates the nature and function of this channel and suggests that it may well represent the earliest example of artificial water management in Iran.

2. Direct and indirect evidence for artificial irrigation in the Near East

Artificial water management in the ancient Near East has been identified as one of the key innovations of the sixth millennium BC, which was to set many communities "on the path toward population expansion and urban life" (Hole and Flanney, 1967, pp. 181). Certainly, a more reliable water supply for cultivation in arid areas where rainfall was erratic could ensure greater crop returns, but socially the impact was far greater as "the construction and maintenance of this system…required greater labour than dry-farming, and also added a new dimension to the alteration of the

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doi:10.1016/j.catena.2009.02.009

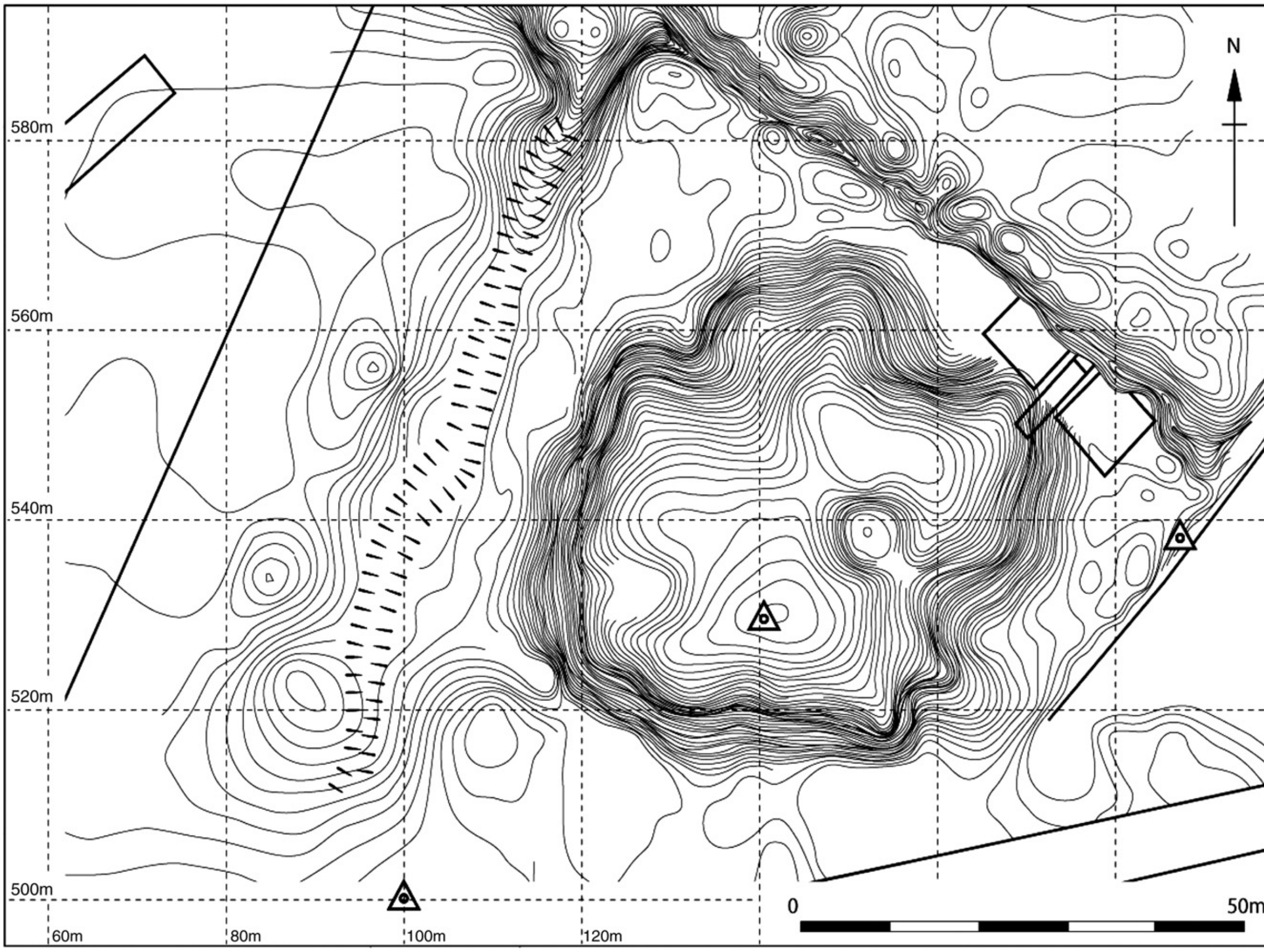

Fig. 1. Survey of the Tepe Pardis site showing archaeological excavations. Boxes represent archaeological excavations.

natural landscape. Fields became improved property on which labour had to be spent regularly" (ibid., pp. 202). Rather than pursuing direct evidence of channels and ditches, these early pioneers restricted their efforts to the study of indirect evidence, in the words of Frank Hole and Kent Flannery "There are two lines of evidence for early irrigation. One is the… distribution pattern of sites with regard to fossil stream channels…The other line of evidence concerns the size of seeds of flax or linseed" (1967, pp. 182). With reference to the former line, Adams suggested that during the 'Ubaid period most small villages were located close to natural networks of water courses but that thereafter colonization of other areas was possible through artificial water management by breaching levee banks (1965, pp. 35–36). The evidence from Susiana has been augmented from other areas in Iran, albeit from the earlier 'Initial Village Period' c. 8000–5000 BC identified by Hole. For example, Ali Kosh in the Deh Luran plain was located next to a natural lake whilst its successor, Chagha Sefid, was closely associated with a seasonal stream (Hole, 1987).

This first line of indirect evidence is joined by the second, which concerns the nature of the species and size of plant remains recovered from archaeological sites. Indeed, such was the conviction of academics that it was possible to link such remains to the presence of irrigation, that one of them stated "We need not, in fact, look beyond the plant table to find proof of significant changes in crop choice, indisputably pointing at an intensification of human mastery of growth conditions, an advance that can only be ascribed to control of the water supply." (Helbaek, 1969, pp. 416). Helbaek based his statement on comparative palaeobotanical evidence from the successive sites of Ali Kosh and Tepe Sabz, having linked the presence of six-row barley, lentil and flax at the latter to "the inception and development of irrigation" (ibid., pp. 410). Whilst these plants are certainly associated with moister environments than those of the Deh Luran plain, his hypothesis is somewhat weakened by the fact that linseed flax and lentil were also recovered from Ali Kosh, but he dismissed the presence of irrigation from these early levels suggesting that they were "evidence of trading contact and repeated import of foreign seed from the mountains to the north" (ibid., pp. 397). Additional indirect evidence for irrigation takes the form of 'polished celts' from the Sabz Phase (c. 5500–5000 BC) which would have been well suited to cut irrigation channels and diverting watercourses, a view that has been advanced by Frank Hole (Hole et al., 1969, pp. 355). Despite these two important strands of indirect evidence supporting the general assumption that artificial irrigation had spread across the region by the 'Ubaid period (c. 5900–4200 BC), direct evidence has only been identified at a single site, Choga Mami. Choga Mami is a tell site located in eastern Iraq on an alluvial fan close to the town of Mandali (Oates and Oates, 1976). Joan Oates excavation of an area that stood some 3 m above the surrounding fields exposed a sequence of six channels on the edge of a settlement occupied between the Samarra (c. 6000 BC) and 'Ubaid period (Oates, 1969, pp. 123). Measuring two metres wide, the first two channels (A and B) were interpreted as natural watercourses, but later channels C, D, E and F were identified as artificial water channels diverting the supply around the expanding settlement (ibid., pp. 125; Oates and Oates, 1976, pp. 132). Additional, indirect evidence was also found at the site in the form of lentils and six-row barley (Field, 1969 pp. 140–143). This unique example, found almost forty years ago, has provided evidence for scholars that formative experiments of

Fig. 2. View of the tell site from the north looking across the quarry. Note the car to the left for scale and the road. The irrigation channel is marked (X) on the above section.

manipulating natural watercourses to irrigate fields are likely to be found on the lower slopes of alluvial fans (Wilkinson, 2003, pp. 74).

3. Tepe Pardis and the Tehran Plain

In line with this prediction, an example of a possible artificial irrigation channel, at Tepe Pardis, is also located within the lower stretches of an alluvial fan, the Jaj Rud in Iran's Central Plateau. The watershed of the Jaj Rud is the main ridge of the Elburz mountains and the catchment feeds water and sediment to a fan of more than 2500 km^2 that extends from the southern margins of the mountains, through the densely settled Tehran plain, down to salt desert or kavir (Beaumont, 1972). The tell site of Tepe Pardis lies within this area and was identified by a collaborative archaeological team made up from the Universities of Tehran, Durham, Leicester, Kingston and Bradford in 2003. This site was under threat from a clay quarry that surrounded it on three sides (Coningham et al., 2004). A step trench was excavated down the northern face of the tell (see Figs. 1–3), revealing a 10.5 m deep sequence that extended from the late Neolithic to the Chalcolithic; that is, from the sixth to the fourth millennia BC (Coningham et al., 2006; Fazeli et al., 2007). Although badly damaged by the quarry, the truncated sides of Tepe Pardis exposed an invaluable 3.5 m deep sequence of cultural features and old land surfaces (Gillmore et al., 2007).

At the same level as the Neolithic ceramics and mudbrick structures, a cross-section was also exposed that had the characteristics of a small channel-like structure that ran directly north–south and perpendicular to what appear to be later natural channels higher in the sequence. Identifying the natural and anthropogenic origin of this ancient channel-like feature clearly has great significance for interpreting agricultural

Fig. 3. Archaeological excavation along the north face of the tell. The irrigation channel was located just out of view to the right at the base of the section.

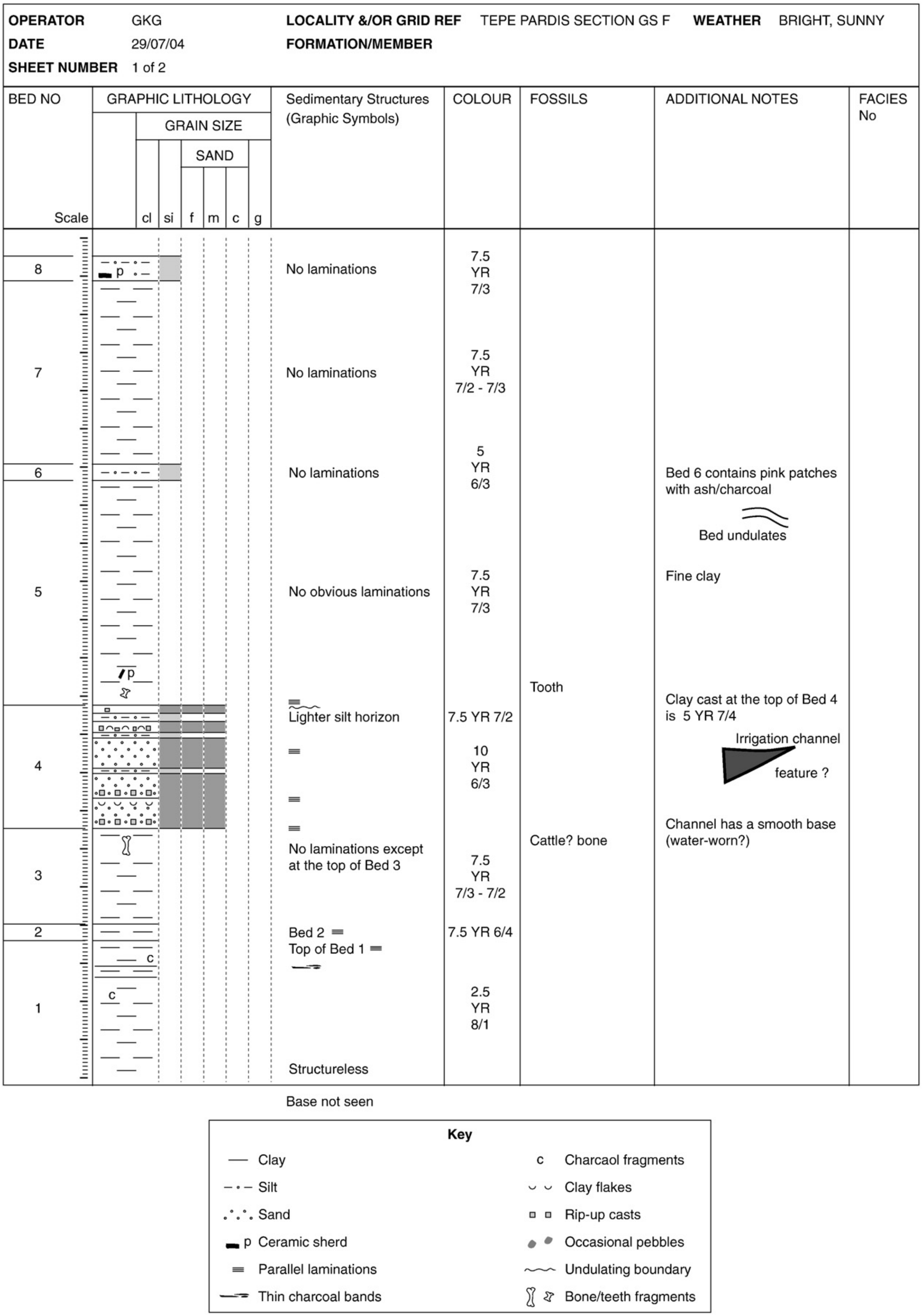

Fig. 4. Sedimentological log through the excavation channel section GSF along the north facing section cut through the tell by quarrying activity.

developments and land use in this archaeologically important region from the late Neolithic to the early Chalcolithic.

4. Landscape and climate

4.1. Summary of the field evidence

Sediment characteristics and sedimentary structures, such as bedding, lamination and ripples, were recorded in the field using standard approaches, including graphic logging (after Tucker, 2001, 2003) with ten detailed graphic logs being taken within the Tepe Pardis quarry site. These logs recorded sediments that are between two and four metres in height. The position of each logged section was located using GPS. On the north facing quarry section, at site GSF (GPS site GS8), a small channel feature in a two metre high sequence was logged, which may represent an early irrigation channel. It was radiocarbon dated to c. 5220–4990 BC. The feature is adjacent to trench II and its generalized sedimentary sequence is summarised below and shown graphically in Fig. 4.

4.1.1. Youngest

Unit 1. Thickness is 1.35 m. Clay with no obvious laminations with Chalcolithic pottery and charcoal fragments. Thin silty horizons amongst clay with no laminations (colour sometimes pinkish, 5 YR 6/3), some pottery sometimes with ash. Occasional small pebbles/granules and bone fragments. Channel-like structures contain fine ash. The bases/tops of channel infill beds are often uneven. Colour generally 7.5 YR 7/3.

Unit 2. Infill deposits. Thickness is 0.24 m approximately. Parallel laminated. Triangular shaped channel feature with smoothed base (water worn?) (0.17 m thick at the logged site). Grain sizes vary from gravel (rare) to sand and silt with some clay. At least 3 fining upwards sequences are present. Rip-up clasts at the base of beds contain clay flakes and lighter coloured silt horizons. The colour is usually 10 YR 6/3.

Unit 3. Oldest. Thickness is 0.32 m. Basal clays (mostly structureless and base not seen) with charcoal fragments and occasional charcoal bands, with parallel laminations in thin beds and near the base of the overlying channel. The deposits colour varies from 2.5Y 8/1 to 7.5 YR 7/3 to 7/2.

Detailed investigations have been carried out of other sequences at the Tepe Pardis site (Log sections GSA to GSC and GSK), that have revealed a younger river system with natural channels that have left behind lenses of sand with epsilon cross-bedding (see Fig. 5). This was seen particularly well at Log Section GSK and at the top of the sequence at GSB2 and GSC. These channels are representative of meandering streams and fairly permanent water systems, and are probably less than a 1000 years old based on radiocarbon dating and stratigraphic analysis, although results of TL analysis are awaited. This analysis has been accompanied by geomorphological research focussed on the Jaj Rud alluvial fan system (see Beaumont, 1972) on which Tepe Pardis is located. A literature-based survey of fans in the region has been complemented by field walking to assess the nature of the modern landscape. It is expected that future quarry investigations will allow us to correlate alluvial units across the fan sequence and build up a regional model of landscape evolution and sedimentation rates. To date, dating of charcoal and bone material has enabled us to comment on sedimentation rates in the vicinity of Tepe Pardis, and make a first step in understanding the processes that have operated on the site during and after Late Neolithic times. For example, it is evident that there has been over two metres of alluvial sediment deposited over the last 1000 years or so. These deposits could have been laid down as a series of minor events, but may have been deposited in a similar manner to the situation proposed by Brookes in his study of the Qara Su basin in central west Iran (Brookes, 1989), who suggested that a significant rainfall event and associated flood had deposited many metres of sediment in his study area around 1000 years before present.

4.2. General quarry sequence

The sequence of materials at the Tepe Pardis quarry site coarsens upwards from fine clays (fine laminations occasionally preserved or without a clear sedimentary structure possibly due to constant wetting and drying by groundwater at some stage) to thin sand horizons with clays with ripple laminations and then to channel-like sedimentary structures with a sandy fill. The latter occur at the top of the sequence within the quarry near the Tepe running roughly parallel to the north side (with similar but more distinctive and substantial sequences elsewhere in the quarry) and can be seen to be horizontally persistent. In general these beds, which is typical for fluvial sands, are sharp based and cross-laminated (Tucker, 2001). Some boundaries at the base of the sand beds contain rip-up clasts from underlying clays

Fig. 5. Channel sands (lenticular in gross morphology) exposed at Tepe Pardis.

Fig. 6. Triangular shaped channel like structure at base of the north facing section at Tepe Pardis.

which may be rounded but are often quite angular. These sediments form beds that represent watercourses that have often reworked older channels. Some of the watercourses also contain clay flakes suggesting drying out of the area followed by high(ish) rainfall/water flow (possibly river flooding). Typical channel sands may be lenticular in cross-section (as are some at the Tepe Pardis site), or may be laterally more persistent as a result of channel or point-bar migration (Tucker, 2001, 2003). Features of this type have been seen at the study site. These deposits are illustrated in Fig. 5 and often show epsilon cross-bedding (sensu Allen, 1963; see also Alexander, 1992). Hunt et al. (pers comm.; see also El-Rishi et al., 2007) suggest that such cross-bedding may represent the infill deposits of single-channelled (sometimes meandering) perennial watercourses. Although such streams were normally perennial, they may have sometimes dried-up as suggested by the evidence set out above. It is possible that water feeding the channels may have been partly from groundwater-rich sediments associated with the Jajrud alluvial fan (see Beaumont, 1972 for details of this particular fan) as well as from surface flow and precipitation (see Hunt et al., 2004 for comparisons with similar sediments in the southern Levant). The cessation of this fluvial environment may have been caused by the main watercourse moving elsewhere, or be a consequence of increasing aridity. The meandering watercourse towards the top of the sequence indicated by epsilon cross-bedding suggests that there may well have been climatic conditions that are different from todays arid with seasonal rainfall, which creates discharges that are not especially flashy (see Briggs and Gilbertson, 1980). Significant aggradation is not normally associated with meandering watercourses (Barker and Hunt, 1995; Briggs and Gilbertson, 1980; Hunt et al., 2004) and according to Hunt et al. (pers comm.; see also El-Rishi et al., 2007) they usually occur in landscapes with significant ground-cover. One interesting contrast with the epsilon cross-bedded Early Holocene beds from Jordan discussed by Hunt et al. (2004) is that there are no shelly remains within or around the cross-bedded channels at the Tepe Pardis quarry site. This could be explained if there had been periods with high flows, followed by periods of drought.

Further investigations during the 2006 field season of the surrounding quarries to the north and west of the site revealed more watercourse sequences containing coarse channel sands and gravel horizons. Significantly these watercourses run roughly parallel to the watercourse noted close to the Tepe. The largest of these consisted of a series of channel sands that extended to around 30 m in width. The main channel structure was approximately 3 m in depth showing cross-lamination. Associated with these well-sorted sands were gravel lags (typically 0.5 m in depth and 1.5 m across) indicating episodes of high energy flow. No pottery was seen in this large channel sequence, although historic material was noted stratigraphically above in the finer clays.

The laminated muds recorded at Log site GSC immediately to the east of the irrigation channel section could represent deposition in a small lake or ponds that formed part of a floodplain sequence. The

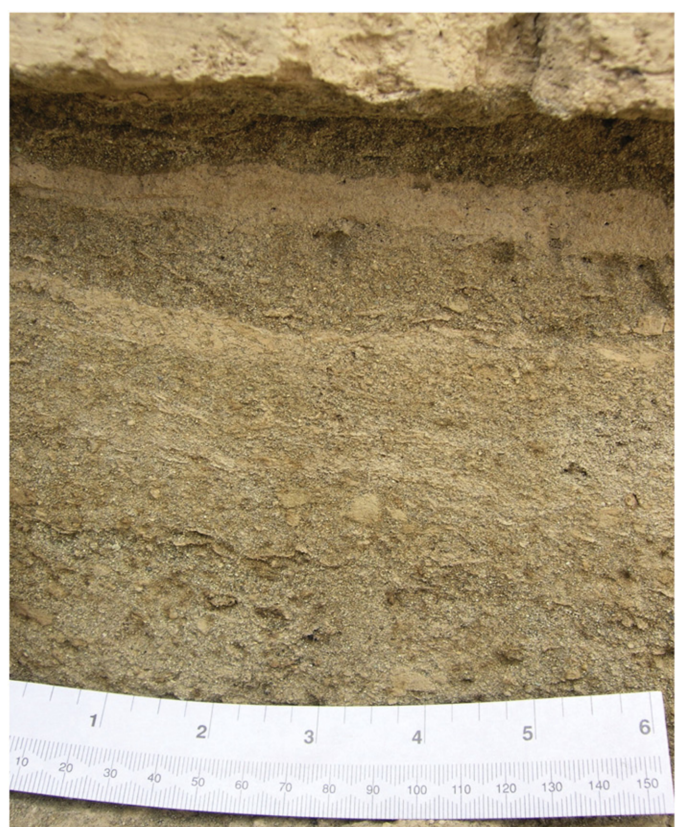

Fig. 7. Infilling material in triangular shaped structure.

Fig. 8. Modern river deposits near Varamin illustrating clay flake formation.

suggestion that there were shallow water bodies would be supported by the occurrence of rare preserved ripples. However, these fine sediments sometimes do not show clear laminations and appear to contain wind blown material.

The section along the north facing edge of the Tepe site is of particular interest for this study. It contains whitish clay that seems to be present in channel-like structures. These structures do not show clear laminations (except at the base of the sequence) and appear to represent slope-type deposits of clay with clay intraclasts and charcoal and ash. The presence of ash-rich beds with potsherds and bones suggests local use of fire. These sediments are thicker in what may have been natural hollows and there are occasional thin silty horizons. These sediments are certainly in part water lain. Butzer (1982) suggests that water lain deposits associated with mounded village sites often demonstrate water sorting with alternating lenses of clay/silt and rubble/sand, and are usually partly laminated. However, the general absence of lamination and the mixture of fines with what could be rubble (the intraclasts?) suggests some sliding due to gravity or water-assisted gravitational sliding may have taken place (Butzer, 1982). The angle of the contact at the base of some of these beds with the underlying material is however generally much less than 25°. Associated with these sediments, towards the base of the exposed sequence, is a particularly distinctive small canal-like feature.

This feature (see Fig. 6) towards the base of the log section at site GSF (Fig. 4) was 1 m across and 24 cm deep with a triangular cross-sectional profile, with a straight (possibly cut) vertical edge on one side, a flat top and an inclined base that, significantly, lacked any semblance of being curved.

The infill was equally distinctive (Fig. 7). It consisted of silty sands with clay-flakes, together with more irregular clay inclusions that may be rip-up clasts. These sediments were horizontally laminated. Tucker (2001) states that fluvial conglomerates are often polymictic with extra- and intra-formational clasts and these materials conform to this.

Modern river sediments have been compared to those observed at Tepe Pardis. Fig. 8 illustrates the types of deposit laid down when a local modern watercourse dries out. The fine clay laminae dry and curl-up to form thin clay ‘shavings’ which are distinctive when observed in sediments in cross-section. The clay flakes preserved in the triangular canal cross-section show this character and demonstrate that fine sediments dried out from time to time, at the time they were deposited.

Above this triangular feature, as suggested earlier, the sequence consisted of a series of sediments made up of charcoal, clay fragments/intraclasts, a few rounded pebbles (river-derived) and Chalcolithic potsherds. The latter occur throughout this sequence. Clays further west along this face (log section GSJ) tend to be fairly structureless with potsherds scattered throughout that appear to be younger material with some well rounded pebbles. The latter form rare impersistent bands.

As noted under Unit 1 above some pink horizons occur in the clay sequence. These are very thin clay horizons, often only a centimetre or so thick, which are also often finely laminated, sometimes undulate. Interestingly, Oates and Oates (1976) noted thin horizontal bands of a fine-grained red deposit at the edge of the Choga Mami mound within water-laid clays. Oates and Oates (1976) suggested that these deposits were similar to those observed elsewhere which were the result of flash-floods in modern seasonal watercourses.

5. Results — laboratory evidence

5.1. Sampling and grain-size analysis

The study of sediment texture in the laboratory involves an analysis of grain-size and grain-size parameters, grain morphology, grain surface texture and sediment fabric (Tucker, 2001, 2003). These textural characteristics are referred to as textural maturity and the texture of a sediment is largely a reflection of depositional processes (Tucker, 2001) which are greatly influenced by climate. The key diagnostic attributes of sedimentary materials are often grain-size and

Table 1
Tepe Pardis quarry site sedimentary analysis results.

Sieve (Φ)	GSF Irrigation channel (TP 04)	GSK, Natural river channel
−1	0.97	0.16
−0.5	4.73	14.61
0	7.47	27.38
0.5	10.29	39.87
1	13.09	52.38
1.5	17.70	60.92
2	28.38	70.66
2.5	66.01	88.49
3	84.13	93.65
3.5	92.94	97.37
4	98.54	99.40

Table 2
Karaj river section sedimentary analysis results.

Sieve (Φ)	RSB1 (b)	RSA 1	RSA 2	RSC 1
−1	0.14	0.12	0.46	30.87
−0.5	0.46	0.86	1.45	45.37
0	0.71	1.25	2.52	55.72
0.5	0.73	1.69	3.41	65.53
1	0.97	2.30	4.26	73.58
1.5	1.24	3.98	9.67	80.25
2	1.53	16.75	19.21	86.00
2.5	4.19	55.35	38.62	93.45
3	29.52	81.93	57.43	96.74
3.5	68.07	92.83	74.07	98.92
4	90.05	97.63	89.58	99.78

The above Karaj river section samples were taken in order to compare ancient channel sediments in Tepe Pardis with those of a more modern nature. This data is awaiting further statistical manipulation for palaeoenvironmental interpretation purposes.

grain-size distribution. Samples were therefore taken for detailed granulometric analysis so that the materials key attributes could be determined.

When deciding which techniques to use comparisons were made in the literature between laser particle-size analysis, dry sieving and the sieve-pipette method. A laser particle analyzer can provide a very accurate grain measurement of particle sizes, however, a number of authors (e.g. Beuselinck et al., 1998) have suggested that laser diffractometry may not provide accurate results for fine platy materials. As much of the material to be examined in this survey was fine-grained, it was decided to apply the classic dry-sieving method for sand-sized materials, with the sieve-pipette method (using settlement columns and a constant temperature water bath) for finer materials. Indeed, Beuselinck et al. (1998) and Scott-Jackson and Walkington (2005) go so far as to suggest that this may be the most appropriate method for such fine materials. The methods followed for dry sieving are presented clearly by Friedman and Johnson (1982), Prothero and Schwab (1996) and Jones et al. (2000). However, mechanical analysis of sediments should not according to Vita-Finzi (1971), be used in isolation (see also Melton, 1965).

The samples were split to produce representative 50–100 g subsamples. They were washed to remove soluble salts and oven dried (at 65 °C). Samples were then weighed and the mass recorded. Standard dry-sieving methods were applied, as were measures of central tendency and dispersion (see Folk, 1966; Walford, 1995). GRADISTAT 5.0 was utilised to plot these (e.g. skewness, kurtosis; see Blott and Pye, 2001). The results (illustrated in Table 1 for Tepe Pardis and Table 2 for the Karaj river) were then plotted as frequency histograms and on cumulative frequency curves (see example Fig. 9A–D for Tepe Pardis).

A sample taken from the irrigation channel (GSF Irrigation Channel, Fig. 9A, B) when analysed suggested a unimodal poorly sorted sediment (after the Folk and Ward, 1957 method, logarithmic mean of 1.043 phi), with a coarse skew (−0.231 phi) and a very leptokurtic distribution (1.878 phi; in other words a high peak, a normal curve having a value of 1.0 according to King, 1975), with a dominant grain size (mean) of fine sand (2.193 phi). Poor sorting (or

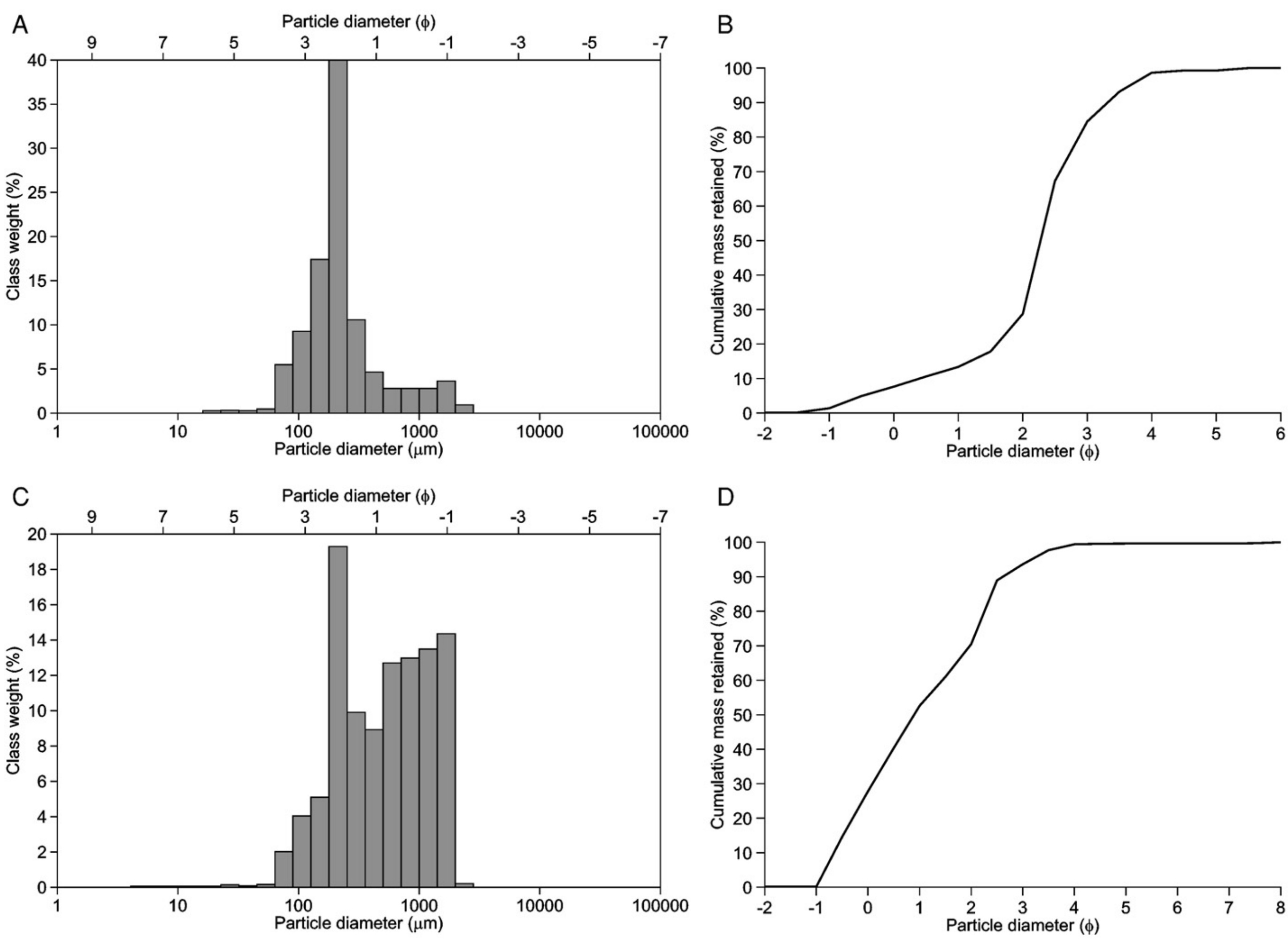

Fig. 9. Sample plots for sample GSF, irrigation channel, together with an arithmetic cumulative frequency curve (A, B), and the same plot for sample GSK, river section at Tepe Pardis (C, D). Plots generated by GRADISTAT. Note the unimodal nature of sample GSF and the bimodality of GSK.

Table 3
Weight and description sub-samples A–K.

Sample number	Quantity (ml)	Weight (g)
GSA A	10 ml	20 g
GSA1	10 ml	38 g
GSB	10 ml	35 g
GSF	10 ml	47 g
GSK	10 ml	47 g

the spread of the grain sizes around the average) of these sediments (GSF) suggests that they may have been deposited quickly. The coarse skew is perhaps unusual for a river deposit because much fine material is usually trapped between larger grains. Beach sands tend to have an excess of coarse material in the 'tail' of the distribution because the finer components are carried away by wave action (see Tucker, 2001). Dune sands on the other hand may show a high kurtosis value and a positive skewness (with a tail of fine material) due to the small amount of fine silt in the sediment (King, 1975). They also tend to be better sorted than river sands. Perhaps the particular characteristics of sample GSF suggests flood events with coarse material being deposited and finer material being carried elsewhere before deposition (or possibly with some winnowing by wind action). This sample belongs to the textural group "Slightly Gravelly Sand" according to Blott and Pye (2001) after Folk (1954), being 1% fine gravel, 97.6% sand (mostly fine) and 1.4% 'mud'. Some samples from Tepe Pardis showed a bimodal distribution with cumulative frequency plots showing 2 inflection points. Sample GSK (see Fig. 9C, D) from a river channel was bimodal, poorly sorted, with a mean of 0.942 (coarse sand), sorting of 1.303 (poorly sorted), a symmetrical distribution (0.088) and platykurtic (having a flat-topped peak). The cumulative frequency curve is steep compared to that of GSF. The existence of bimodal sediment implies modes of behaviour in entrainment and transport that are distinctive from unimodal sediments (see Evans and Benn, 2004; Wilcock, 1993). Very high (or low) values of kurtosis suggest sorting in a region of high energy, then transportation without a change in the character of that material to another environment, where it is mixed with another sediment, possibly in a low energy environment (King, 1975), producing a bimodal distribution.

Bull (1962) undertook a study of alluvial fans examining the size distribution of samples from the Diablo Mountains in California. The samples were collected after the rainy season and analysed for grain size distribution mechanically (as in this study) and plotted using logarithmic graphs. In the region studied the vegetation is limited while the streams are subject to flash flooding. Bull (1962) was able to identify two types of sedimentary environments — stream channel and braided stream. He was able to demonstrate that mud-flow deposits showed some similarity with turbidity current sediments, having a greater density than traction current deposits. The sediments deposited at Tepe Pardis are alluvial fan in origin, with channels (e.g. samples GSF and GSK) being analysed in detail.

The GRADISTAT programme was designed for unconsolidated sediments. The sediments encountered in this study in the more sandy horizons were suitable for this analysis. However, some of the finer clay-rich sediments were relatively well-cemented with a calcareous cement and this proved problematic when trying to assess grain size.

Grain-size properties are related to the dynamic conditions under which transport and deposition occurs. Trends in grain-size can be used, for example, to suggest the direction of sediment dispersal. With conglomerates, it is useful to measure the maximum clast size and bed thickness as this will give an indication of the competence of the flow (Tucker, 2001). However, there were few gravel-sized clasts encountered in the bulk of the sediment at Tepe Pardis, but those found were examined for size, shape and roundness characteristics.

5.2. Pollen analysis

Five samples of sediment have been analysed (see Table 3 with weight and sub-sample descriptions) from the Tepe Pardis site in Iran and one from a comparative section on the banks of the Karaj river. The sediments mostly comprise calcareous clay, silt and sands. Only a few samples were collected because the primary objective of the exercise was to ascertain if the samples contained microscopic pollen grains of suitable quantity and quality for further palynological assessments.

The sub-samples were tipped into five 125 ml Pyrex beakers and macerated in 3 mol HCl to break down the carbonates in the sediment. 40 ml of 10% potassium hydroxide (KOH) and 5 mg of sodium pyrophosphate ($Na_4P_2O_7$) was added to each sample. The containers were placed on a sand bath and heated for twenty minutes.

The contents of each beaker were poured through a 140μ sieve onto a Perspex 'swirling' dish. Mains supply water filtered through a Whatman polycap HD disposable filter capsule was used to swill the macrofossils contained within the sieve, with the liquid running onto the swirling dish. The macro remains were collected for microscopic examination. The liquid contained within the swirling dish was then agitated gently until a ring of sediment had formed on the base of the dish. The swirling dish was then tipped into a 6μ sieve, leaving the majority of the sediment on the base of the swirling dish to be run to waste. The 6μ sieve was then filled with filtered mains supply water and rinsed to remove all trace of the alkalines — KOH and $Na_4P_2O_7$. Following the final rinse 2 × drops of Safranin 0 solution 1% was added

Table 4
Results of preliminary pollen analysis of samples from Tepe Pardis.

	GSA section A, clay just above pottery horizon	GSA1 (TPO4) near bone horizon	GSB, clay 1 metre from base	GSF, irrigation channel	GSK, clay beneath natural channel
Poaceae	1	0	8	0	1
Chenopodium	7	5	7	3	1
Oleaceae	0	0	1	0	0
Algal cyst	2	0	6	0	2
Dinoflagellate cyst	2	0	3	0	0
Indet	0	0	3	5	2
VAM	0	0	32	0	4
Fungal spores	17	0	8	0	25
Soil fungi	0	0	3	0	0
Thermally Unit mature	10	15	53	200	366
Diatoms	0	0	0	0	0
Pinus type	0	1	0	1	0

Table 5
River section (Karaj comparison).

	RSA2
Poaceae	2
Chenopodium	0
Oleaceae	1
Algal cyst	4
Dinoflagellate cyst	8
Indet	5
VAM	9
Fungal spores	11
Soil fungi	0
Thermally mature	55
Diatoms	2
Pinus type	0

to the solution in the sieve (approximately 2 ml) to stain the pollen grains. The stained solution was then pipetted in phials for storage prior to analysis. Six microscope slides were prepared and four transects from each slide were examined using a Leica Galen III microscope.

The assessment of the sediment from Tepe Pardis quarry indicates that pollen (and other useful microfossils) have been preserved in the sediment from the excavated site, although their occurrence is very sparse. As a result of the harsh background matrix, specifically clastic sediments that are lime-based and subject to regular episodes of flooding and subsequent drying, it is not surprising that pollen analysis has yielded limited results. Although findings are preliminary, the local environment at Tepe Pardis was in part one of slow flowing or standing water, as indicated by the presence of dinoflagellate cysts, algal cysts and diatoms. The pine pollen may well have been transported by water, although this provides a useful general environmental backdrop, as does the presence of olive species. The presence of grasses within the burnt plant material is notable as is that of vesicular carbuncular mycorrhizal and soil fungi, both of which indicate soil erosion. Although very preliminary, the results that have been obtained to date offer a valuable adjunct to our other environmental data, and certainly warrant further investigation and the collection of larger samples during the next season.

The results of the pollen analysis is shown in Table 4, with comparative material from the Karaj river in Table 5.

5.3. Dating

As pointed out by Tucker (2001) fossils are uncommon in fluvial sediments and are mostly of plant material or skeletal fragments of freshwater and terrestrial animals. Charcoal and animal bone fragment were collected near the channel feature, from layers stratigraphically above and below this channel, in order to place it within a date range.

The pottery fragments from this site have been assigned to Late Neolithic, Transitional Chalcolithic (c. 5300–4300 BC), Early Chalcolithic (c. 4300–4000 BC) and Middle Chalcolithic (c. 4000–3700 BC) (see Fazeli et al., 2004).

The 10 radiocarbon measurements were all carried out on charcoal by the Oxford Research Laboratory for Art History and Archaeology. In addition to the radiocarbon determinations, there were stratigraphic records from which the relationships between the contexts and their assorted radiocarbon samples could be determined. Initial calibration of the radiocarbon determinations was carried out using OxCal V2.18 (Bronk Ramsey, 1995), based on the internationally agreed calibration curve of Stuiver and Reimer (1993) and the radiocarbon ages are shown in Table 6. According to Coningham et al. (2006), when looking at the initial probability distributions of calibrated dates from the Anuradhapura site in Sri Lanka, a number of effects were evident. The dates for example were earlier than the radiocarbon determinations; in some cases the radiocarbon calibration resulted in multiple ranges

Table 6
A summary of radiocarbon dating results, Tepe Pardis.

Part of Site	Context	Sample no	Material	Identification details	Reference Code	Delta 13C	C14 Determination	Date at 95% probability	Date after statistical inference at 95% probability
Trench I	4	2	bone	thoracic spine – cattle	OxA-14736	-15.4	1967 ± 31	50BC-90AD (94.3%) 100AD-120AD (1.1%0	50BC-120AD Not included in analysis
Trench I	8	3	bone	long bone fragment	OxA-14738	-15.2	5050 ± 35	3960BC-3760BC	3960BC-3770BC
Trench I	5	11	charcoal	*Tamarix* sp.*	OxA-14737	-25.1	5156 ± 37	4050BC-3930BC (79.4%) 3880BC-3800BC (16%)	4050BC-3920BC (93.1%) 3860BC-3820BC (2.3%)
Trench I	10	4	bone	calcaneus- sheep	OxA-14739	-17.6	5894 ± 37	4850BC-4680BC	4830BC-4680BC
Trench I	12	14	charcoal	fragments too small to identify	OxA-14740	-25.4	6004 ± 38	5000BC-4790BC	4880BC-4740BC
Trench I	14	15	charcoal	*Populus* sp.*	OxA-14741	-23.9	5928 ± 35	4910BC-4710BC	4900BC-4780BC
Trench I	17	5	bone	long bone fragment	P16748	Fail			
Trench I	20	18	charcoal	fragments too small to identify	P16749	Fail			
Trench I	18	17	charcoal	fragments crumbled when tried to split for identification	OxA-14742	-25.0	5978 ± 38	4990BC-4770BC	4920BC-4800BC
Trench II	1001	21	bone	vertebrae – sheep?	P16951	Fail			
Trench II	1002	22	bone	articulation fragment – sheep?	P16952	Fail			
Trench II	1003	31	charcoal	fragments too small to identify	OxA-14743	-24.2	5976 ± 36	4980BC-4770BC	4950BC-4820BC
Trench II	1008	24	bone	long bone fragments	OxA-14744	-16.2	6000 ± 38	4990BC-4790BC	5000BC-4860BC
Trench II	1014	34	charcoal	fragments too small to identify	OxA-14745	-25.0	6100 ± 39	5210BC-4910BC	5200BC-5170BC (1.8%) 5130BC-4930BC (93.6%)
Trench II	1015	27	bone	bone fragments, bird	OxA-14746	-15.3	6226 ± 37	5310BC-5190BC (49.2%) 5180BC-5060BC (46.2%)	5280BC-5050BC
Trench II	1017	29	bone	long bone fragment, small mammal	OxA-14747	-17.3	6230 ± 45	5310BC-5050BC	5310BC-5080BC
Quarry	G1	37	bone	bird	OxA-14748	-18.3	1018 ± 29	900AD-920AD (1.0%0 970AD-1050AD (89.1%) 1090AD-1120AD (4.4%) 1140AD-1150AD (1.0%)	900BC-1150BC
Quarry	G4	40	bone	long bone fragment	Fail				
Quarry	G6	42	bone	long bone fragment, large mammal	Fail				
Quarry – Irrigation channel	QX	55	bone	long bone fragments	Fail				
Quarry – Irrigation channel	IX	52	bone	long bone fragments	Fail				
Quarry – Irrigation channel	NX	54	bone	sheep teeth, young animal	OxA-14749	-16.1	6152 ± 40	5220BC-4990BC	5220BC-4990BC
Quarry – Irrigation channel	DX	51	bone	long bone fragment, cattle size?	OxA-14750	-19.0	6153 ± 38	5220BC-4990BC	5220BC-5030BC

* neither identification is for a particularly long-lived type.

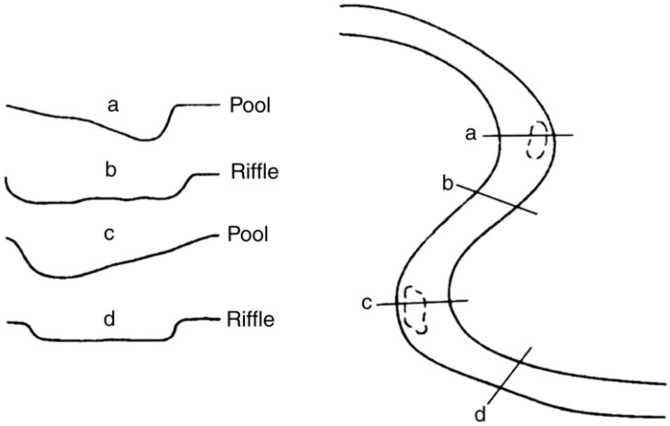

Fig. 10. Pools, riffles and channel cross-sectional forms (Morisawa, 1985).

at the two and, more commonly, the one standard deviation confidence levels; and the age range was increased. In order to utilise radiocarbon determinations to their full extent, use was made of the calibration and analysis program OxCal (Bronk Ramsey, 1995). The radiocarbon determinations for Cheshmeh-Ali were reinterpreted using OxCal, taking into account the stratigraphic information available; namely that contexts were in simple stratigraphic order and that material used in the radiocarbon determinations was securely from within the phases to which the dates are attributed, but could be from any date or sequence within that phase. The archaeological evidence supported this interpretation. It can be seen that the stratigraphic information serves to constrain the calibrated dates to much narrower ranges. The percentages are an index of how well the chronological model agrees with the dating evidence; in some cases the agreement is better than expected and is greater than 100%, in other cases it is poorer.

We are able, therefore, to suggest an end of the Late Neolithic and a beginning to the Transitional Chalcolithic at c. 5300 BC and an end to the Transitional Chalcolithic and a beginning of Early Chalcolithic at c. 4600 BC. Unfortunately, as our sequence does not extend before the Late Neolithic or after the Early Chalcolithic we are unable to propose further boundaries based upon our data from Cheshmeh-Ali.

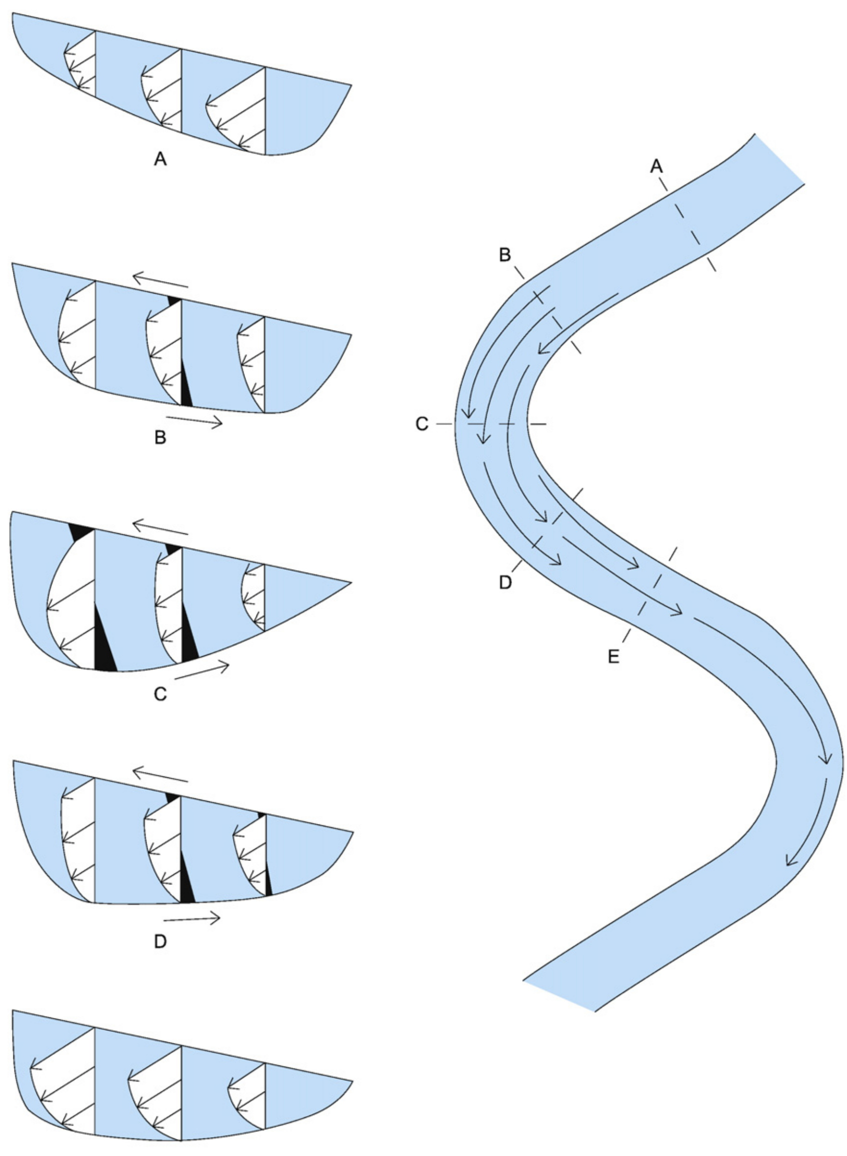

Fig. 11. Idealized flow patterns in a meandering stream. The left hand cross sections show velocity vectors in the downstream direction. The triangular blacked areas are the lateral components of the velocity. The figure on the right-hand side illustrates the streamlines at the surface of the meander (from Leopold and Langbein, 1966). Note how channel cross-sections vary.

6. Discussion

There are a number of factors that need to be reviewed when attempting to determine whether the above channel feature and its infill deposits are the result of deliberate excavation. Firstly, the cross-profile has a distinctive triangular outline, with a near-vertical edge and an angled but straight cut base, which supports the idea that this was a deliberately excavated channel (see Fig. 6 and Log Section GSF, Fig. 4). These features cannot be explained as simply a result of the geometric relationship between the alignment of the feature and the plane of the vertical exposure-excavation face and are unknown from studies of "natural" channels (see Cooke and Doornkamp, 1974; Cooke and Warren, 1975; Leopold and Langbein, 1966; Morisawa, 1985; Reading, 1996).

Secondly, it is clear from this research that fluvial channel cross-sections are complex landforms due to a variety of causes. These include the velocity of the water flow not being constant in depth or across the whole channel width; the position of regions of maximum turbulence in a channel will vary across the cross-section influencing the maximum position of river-bed scour (and hence pools and riffles); the fact that natural channel cross-sections can vary very rapidly over very short distances. Natural channels vary in cross profile depending on where the cross-section is in relation to bends and crossovers in a meandering stream (see Figs. 10 and 11). For example, a channel profile where riffles exist tends to be shallow and flat bottomed, while the profile across pools tends to be asymmetric being deeper on the outside of the bend and shallow on the inside (where point bars may build outwards; see Figs. 12 and 13). However, Vita-Finzi (1971, p.140) cautioned that "the form of channels is still a poor guide to the nature of the agency that produced them".

The triangular cross-section feature from Tepe Pardis however, has some features in common with a modern small channel observed on the Tehran Plain next to a modern managed channel (see Figs. 14 and 15). This modern feature appeared to be an overflow channel leading away from the modern irrigation channel. One steep side in the modern irrigation overflow channel appears to be the result of undercutting and the shallow inclined base is also a distinctive feature (Fig. 15). However, here the steep undercut side produced a concave bank with an overhang, rather than the clear edge observed in the triangular feature. This overhang would however, collapse into the stream bed with time and may produce a similar triangular cross-section to that of the archaeological channel. Although the irrigation channel displayed in Fig. 14 has a shallow square-edged profile about a metre or so wide, smaller irrigation channels (0.5 m to 0.75 m in width) observed in the vicinity had a triangular profile being cut by a 'chop and drag' approach using a simple tool such as a hoe or adze.

One interesting aspect of the above channel is the apparent lack of upcast material. Such canals may be fringed with linear spoil mounds that form banks in section. These contain clasts of material dug from the original sedimentary plain, or from subsequent clearing. However, such features can be removed by erosion, through the action of wind or water.

The channel cross-section of the irrigation feature at Tepe Pardis does differ markedly in a number of ways from modern natural channels in the area, and from those attributed to natural fluvial agencies at the study site which generally have more scooped bases and sometimes lenticular morphologies. It shows no sign for example, of the lateral migration that is typical of most natural streams (Fig. 16), and all the other fluvially derived channels noted at the study site (see Fig. 5). The cross-sectional profiles of the upper streams in the sedimentological sections at Tepe Pardis appear to be typical for meandering channels — with rounded sides, infilled with cross-laminated sandy sediments that are a characteristic of migrating point-bars (Reading, 1996; Tucker, 2001). Fig. 13 illustrates a modern meandering stream (currently dry due to water extraction for Tehran) exposed near Tepe Pardis. Note the steep but rounded banks and gravel lag deposits.

This evidence is supported by extending the investigation to include both the deposits within the channel and the deposits that occur beneath, adjacent to and above the triangular channel feature — Vita-Finzi (1971) emphasized that infill fluvial deposits may be more informative than landforms in explaining origins. These infill sediments were distinctively horizontally-laminated, silty sands with clay-flakes preserved, together with more irregular clay inclusions that may be rip-up clasts, and they did not extend beyond the triangular channel. The stratification observed within the triangular channel does not display any indications of the lateral migration or re-working that are associated with meandering or braided flow conditions. In this situation, these characteristics suggest a channel with quiet, even water flows, that on occasion experienced complete desiccation to produce clay pans, polygonal cracking and subsequent fluvial re-working of these clay pellets within the further fluvial sediment. Evidence of episodic more powerful flows corresponding with higher magnitude/lower frequency events as occur naturally in the fluvial environment (Calver and Anderson, 2004) is not present.

Fig. 12. Typical gravel-rich point bar development in a Yorkshire stream.

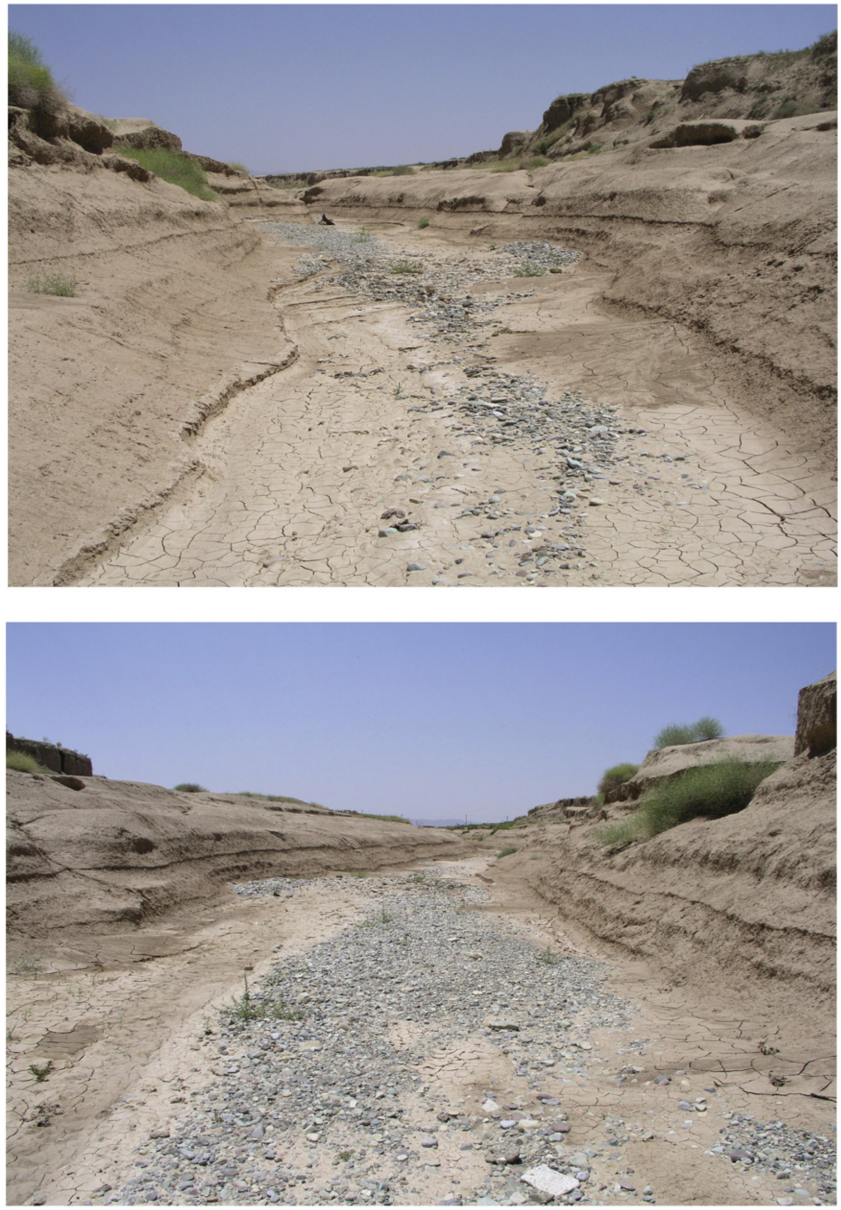

Fig. 13. Modern dry river bed near Varamin. Note the flattish bottom and rounded nature of the channel sides, the gravel lags and point bar development in the distance in the top picture.

In contrast, the fluvial deposits in the modern landscape and that make up the great majority of the Tepe exposure are different. They indicate two types of fluvial conditions — meandering and braided. These are variable in channel cross section. Modern fluvial sediments have been compared to those within the channel at Tepe Pardis, especially in terms of dry phases when a fluvial channel dries out. Comparisons with areas elsewhere suggest that transitions in flow conditions corresponds to less stable conditions that might correspond to any or a mix of (often) inter-related events – more unstable bank margins, loss of riparian agriculture, tree and/or adjacent vegetation, greater intensity of storms or wet season runoff, human activities including farming that might affect rainfall-runoff relationships – typically increased flashiness of discharge.

Investigations of modern-day irrigation channels on the Tehran Plain proved enlightening. Many of these modern channels are of a similar size to the channel-like feature at Tepe Pardis. They are fairly straight in plan and their cross-sectional form is generally a simple rounded groove, although this varied and the smallest of these irrigation channels had an asymmetric form.

There are some striking similarities between the suggested irrigation channel at Tepe Pardis, and a series of small water-channels that Oates and Oates (1976) noted in the Choga Mami mound at the edge of a floodplain (Brown, 2001) in eastern Iraq in a sixth millennium BC sequence. These relict channels were exposed in archaeological sections (Wilkinson, 2003) with irrigation being suggested by the presence of carbonized organic remains. Choga Mami is situated on an alluvial fan with the initial phase of irrigation being suggested as taking advantage of the natural morphology of the fan (Wilkinson, 2003). These small channels, up to 2 m in width and 50 cm deep, were filled with water-lain fine-grained sediments (Oates and Oates, 1976) and were stratified in deposits at the edge of the mound (as at Tepe Pardis). Some of these channels (the deepest in the sequence) were not used for irrigation (Wilkinson, 2003) whilst others clearly were, being above contemporary ground level outside the settlement. These small early channels probably directed water down the main slope of the fan and were in use when the land surface was aggrading (Oates and Oates, 1976; Wilkinson, 2003). This is probably the same or a similar situation noted by this study at Tepe Pardis. Another interesting similarity is that at the Choga Mami site minor channels of the modern fan system skirt around the

Fig. 14. Managed irrigation channel on the Tehran Plain. Note the GPS unit in the left hand bottom corner for scale.

mound immediately above the ancient minor channels (Oates and Oates, 1976). At Tepe Pardis there are younger channel sequences above the suggested irrigation channel, albeit running at right angles.

7. Conclusion

A small canal-like triangular in cross-section feature noted at Tepe Pardis and attributed to the Neolithic is here interpreted as a silted-up artificial channel. Its infill-deposits indicate periods of shallow relatively quiet flow and periods of drying-out. The presence of rip-up clasts in the infill indicates occasional episodes of greater water flow. The sediments in the channel represent at least 3 phases of flooding — there are a number of fining upwards sequences that can be seen in Fig. 7. The sedimentary structures suggest that there may have been episodes of rapid flow with the formation of horizontally laminated bedforms. Therefore, the channel may have acted as a depository for sediments as they settled out of the flood waters. If there was a series of such flood events then horizontal lamination and sorting may be very similar to what can be observed preserved in the channel. One interesting fact that complicates this picture is that there has been no cultural material found to date within the channel sequence, although cultural material surrounds it. The canal and its infill sequence are distinct from the deposits beneath, adjacent to and above it. Fluvial geomorphology can provide a valuable insight into ancient water conservation schemes (Vita-Finzi, 1971). Oates and Oates (1976) point out that the history of agriculture in alluvium is complex and that the practice of irrigation in the alluvial plain requires a certain level of skill. This study at Tepe Pardis, together with evidence from Choga Mami, underlines the fact that 6th millennium farmers in Iraq, and now probably Iran, practised irrigation.

Fig. 15. Modern overflow next to a managed channel on the Tehran Plain. The modern irrigation channel is in the top left hand side of the photograph running from right to left, obscured by shadow.

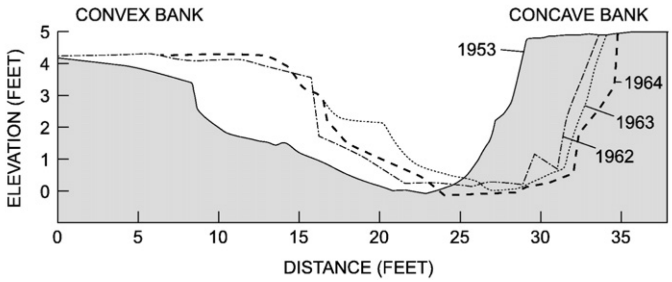

Fig. 16. Lateral migration of a typical meander. This illustrates four successive cross-sections, surveyed on the Watts Branch between 1953 and 1964, a small tributary of the Potomac River near Washington, USA. Note how lateral migration has occurred through erosion of the concave banks and deposition on the convex banks (Leopold and Langbein, 1966).

Finally, this crucial evidence now begs the question of why population expansion and urban life did not develop more fully on the Tehran plain despite this early evidence of irrigation? Was it for example as Fazeli (2001) has suggested, the unreliability of water resources that controlled development? The river sequences at and around the Tepe Pardis site noted in the 2006 quarry surveys provide evidence of variations in flow rate, and migration of watercourses across the alluvial fan surface. One comparative Tepe site visited, Mafinabad to the west of Tehran, provided clear evidence of a migrating braided watercourse approximately 30 m across, exposed in excavations for building work. These braided sequences contained Middle Chalcolithic pottery in abundance in one horizon, with another pottery layer below. The sequences were approximately 300 m from the Tepe site, with no evidence of watercourses in the 2 m of finer sediment exposed above. The sediments themselves consisted of epsilon cross-bedded well-sorted sands, gravel lags at the base of beds, and isolated gravel lenses, much like a sequence noted in the 2007 field season to the west of Tepe Pardis, within the boundary of the quarry site (but without pottery remains). The horizons examined both at Mafinabad and the western channel sequence at Tepe Pardis, generally showed graded bedding, indicating a series of depositional events that decreased in strength of flow. The absence of a later watercourse in the Mafinabad sequence suggests that channels at this time were highly mobile and unreliable.

Another interesting comparison can be made to the Late Neolithic tell of Wadi Faynan, Jordan (Hunt et al., 2007). Here Hunt et al. points out the relationship between the position of the tell and nearby stream deposits. These deposits indicate fairly permanent flows with a 5–20 m wide and greater than 3 m deep channel. Such a relatively reliable water supply with the proximity of uplands could help to buffer society against drought. The importance of water in developing a sustainable society in marginal environments (such as those that exist today on the Tehran Plain) was highlighted by Gilbertson et al. (2000).

Acknowledgments

This work was undertaken as part of a larger project on “Socio-Economic Transformations on the Tehran Plain” supported by the British Academy. The figures were drawn up by Steven Cheshire and Claire Ivison (the latter at the cartography centre, Kingston University).

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